PETRIFIED FOREST NATIONAL PARK,

ARIZONA

WATER RESOURCES SCOPING REPORT

Intermountain Support Office

In cooperation with:
NPS Water Resources Division
and
Petrified Forest National Park

Technical Report NPS/NRWRD/NRTR-2003/313

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NATIONAL PARK SERVICE

DEPARTMENT OF THE INTERIOR

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United States Department of the Interior
National Park Service

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EXECUTIVE SUMMARY

Petrified Forest National Park is located in the arid, high desert region of Arizona along the southern edge of the Colorado Plateau. The park is situated within the Leroux Wash, Lower Puerco River and Upper Little Colorado River watersheds, all of which are tributaries of the Little Colorado River. Streams within the park are ephemeral in nature and only provide surface flow in response to rain and snow melt in the spring, and flash-flooding during the summer monsoon rain season. Surface water is also intermittently available seasonally in small pools (tinajas), springs / seeps, and abandoned stock impoundments. The park also overlies two groundwater aquifers, the Puerco River Alluvial Aquifer and the Coconino Regional Aquifer, also known as the "C Aquifer".

While existing surface water quality information is limited, water quality monitoring conducted by the Arizona Department of Health Services in 1985 indicated that the Puerco River (at the park road bridge) exceeded recommended drinking water and / or acute freshwater standards for arsenic, copper, lead and zinc as well as drinking water standards for uranium and radium 226. This was a particular concern for the park, because until recently, the park's drinking water supply was derived from a well into the Puerco River Alluvial Aquifer, whose source was the Puerco River. However, in 1997, the park began purchasing water from the Navajo Tribal Utility Authority (NTUA) which alleviated potential public health concerns.

This water resources scoping report, authored jointly by the National Park Service's Intermountain Region, the NPS Water Resources Division, and Petrified Forest National Park, was developed in order to assist park management in identifying water-related issues and to provide considerations for future action in addressing these issues.

The "Introduction" (Section I) and "Hydrologic Environment" (Section II) of this report provide a description of the park's water-related resources as well as an assessment of their current condition based upon available data.

Significant water-related issues are identified and discussed Section III of this report. These include issues related to water quality, water quantity, water supply, exotic species management and riparian restoration, erosion, and water issues related to proposed park expansion.

Section IV provides park management with considerations for future actions including: 1) the development of an appropriate water-related baseline inventory and monitoring program; 2) the need for the implementation of a water conservation / drought contingency plan; 3) recommendation for an evaluation of alternatives for public health-related, long-term water quality monitoring of the park's "back-up" water supply (Puerco Well No. 2); 4) an endorsement of currently planned research efforts to evaluate tamarisk control and riparian restoration efforts; and 5) a recommendation to incorporate water-related inventory, monitoring, research, and management needs into park expansion planning.

ACKNOWLEDGEMENTS

Information contained within this water resources scoping report is derived from many sources, including a review of existing hydrologic information pertaining to past and present water resource conditions, discussions with park personnel and subject matter experts familiar with the park, and from observations made during site visits and field trips.

The authors of this report appreciate and acknowledge the full and timely sharing of water resources information by many individuals including Don Bills of the US Geological Survey; Dr. Michael Ketterer of Northern Arizona University; Pat Thompson, Bill Grether, Bill Parker and Chuck Dorn of Petrified Forest National Park; and Carl Bowman of Grand Canyon National Park. The authors also express their appreciation to David Vana-Miller, Larry Martin, Gary Smillie, Bill Hansen, Laura Harte, and Gary Rosenlieb of the National Park Service's Water Resources Division who provided information, technical review and/or editorial suggestions regarding the draft manuscript. Colleen Filippone and Larissa Read of the Intermountain Support Office provided technical review and editorial assistance. Finally, thanks are due to Viktoria Magnis and Kerri Mich of the Intermountain Support Office for their helpful GIS support.

I. INTRODUCTION

Park Location, Legislation, Purpose and Management

Petrified Forest National Park is located in northeastern Arizona, immediately north of the Mogollon Rim at the southern edge of the Colorado Plateau province (Figure 1). Approximately 55% of the Colorado Plateau is managed by federal agencies and 24% of the land is owned by Native American Communities.

The park has land in both Navajo and Apache counties; the county line runs north to south through the park along the R24E-R23E line. About 20% of the park lands are located west of the boundary in Navajo Country. Sizable Navajo and Hopi Reservations are located to the north of the park's boundary and there are additional lands owned by the Navajo Nation located to the east of the northern half of the park. The only community of any significant size is located approximately 25 miles to the west of the park in Holbrook, where the park also owns housing units for some of its staff. To the east, there are a string of very small towns including Navajo, Chambers, and Sanders.

The park is very nearly bisected by Interstate 40, which roughly follows the path of historic route 66 through the southwest.

The northern third of the park is dominated by the Painted Desert. The desert extends beyond the park to encompass an area 350 km long and 80 km wide. Within the park, the eroded mesas and hills of the Chinle formation dominate the landscape. Vegetation is particularly sparse due to rapid erosion and the clay soils. Lithodendron Wash is the primary hydrologic feature of the area.

Petrified Forest National Park's boundaries are the result of a century of expansion, contraction, and adjustment. Much of the land included in the National Park was acquired from private landowners or the State of Arizona rather than reserved from lands already within the public domain. The significance of previous land ownership is discussed in the water rights section.

Petrified Forest National Monument was established on December 8, 1906 by President Theodore Roosevelt under the authority of the Act for the Preservation of American Antiquities, enacted earlier that same year. The Antiquities Act empowered the president to set aside federal land of particular archaeological or scientific significance (Lubick, 1996). The newly established National Monument encompassed an area of 60,776 acres extending between the Puerco and Little Colorado Rivers. Approximately 5% of the monument was acquired from the State of Arizona whereas 21% had been purchased from private landowners (Molina, 1979). The Antiquities Act, however, granted authority to reserve only the minimum amount of lands necessary to care for the objects to be protected. The Monument boundary established by President Roosevelt was a conservative estimate of the area needed to protect the most spectacular petrified wood sites and was proposed without the benefit of an on-site evaluation. After conducting a site visit, George P. Merrill of the United States Museum was of the opinion that the significant petrified wood sites could be preserved within a much smaller reservation. Accordingly, President Taft reduced the size of the monument to approximately 26,000 acres in 1911 (Lubick, 1996).

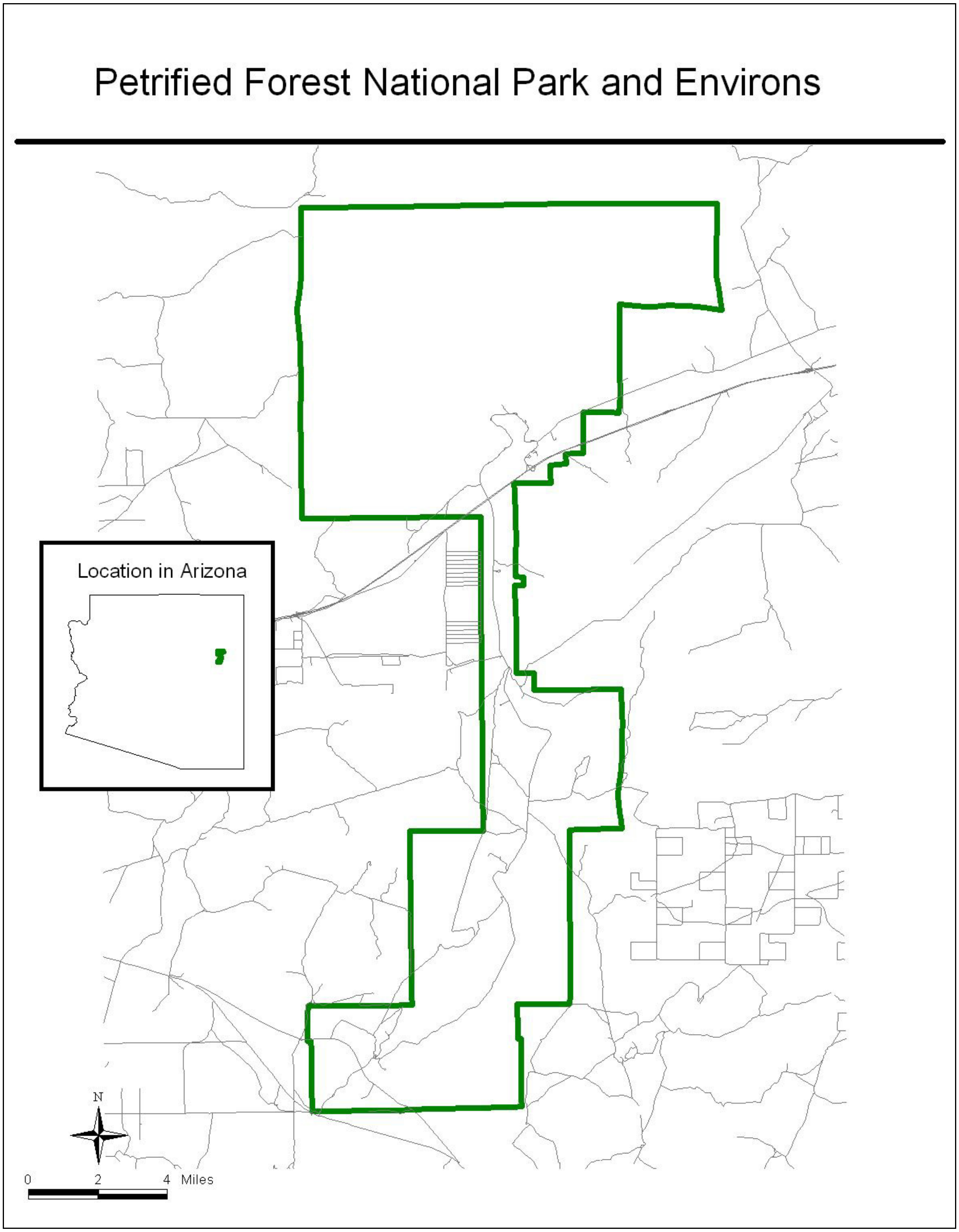


Figure 1. Petrified Forest National Park and environs.

The 1930s saw a re-expansion of the Monument, as land around Blue Mesa and the Puerco River was added in 1930 and 1931 and the Painted Desert became a part of the National Monument in 1932. President Hoover was responsible for the enlargements, which together increased the acreage of the park by 67,578 acres, 37,436 acres of which were obtained from private land holders and 8339 acres of which were acquired from the State of Arizona. In 1958, the National Monument was expanded to 93,493 acres and redesignated a National Park. In 1970, 43,243 acres of land inside the National Park were designated as Wilderness Area (Molina, 1979). In 1986, an additional 40 acres was added to the park, bringing the total size to its current 93,533 acres.

Proposed Park Expansion

Progress has been made toward the incorporation of additional lands into Petrified Forest National Park (Figure 2). The location of the proposed additions is described in some detail in the 1992 Petrified Forest National Park General Management Plan (National Park Service, 1991). The State of Arizona and the Bureau of Land Management (BLM) are currently engaged in a land exchange that will transfer significant amounts of state land on the eastern side of the park to the BLM. The newly exchanged BLM land will be held for the Park Service until such time as legislation expanding the park's boundaries is enacted. Should the legislation, as currently proposed, be passed, it would more than double the size of the park.

Purposes of a Water Resources Scoping Report

The purposes of a water resources scoping report include identifying major water resources-related issues and presentation of relevant information and management considerations to assist the land / resource manager in meeting their management objectives. Typically, a water resources scoping report consists of three major parts.

The "Hydrologic Environment" section provides the land / resource manager with a thorough knowledge of the water-related resources of the area. This retrospective analysis will generally provide a basic description of the water-related resources, a summary of past and current inventory, monitoring, research and management efforts, and the identification of issue-related data gaps.

The "Significant Water-Related Issues" section identifies and discusses the significant water-related issues pertaining to park management. This process is usually initiated with a "scoping session" where land and resource managers, subject matter specialists, and other interested parties come together in order to develop a water-related "issues list". During the scoping process participants are provided an opportunity to identify issues, discuss the management implications of the issues, and to highlight those issues which present the greatest level of concern.

The "Considerations for Future Actions" section provides considerations for further addressing the identified issues, based upon the authors' assessment of the available information.

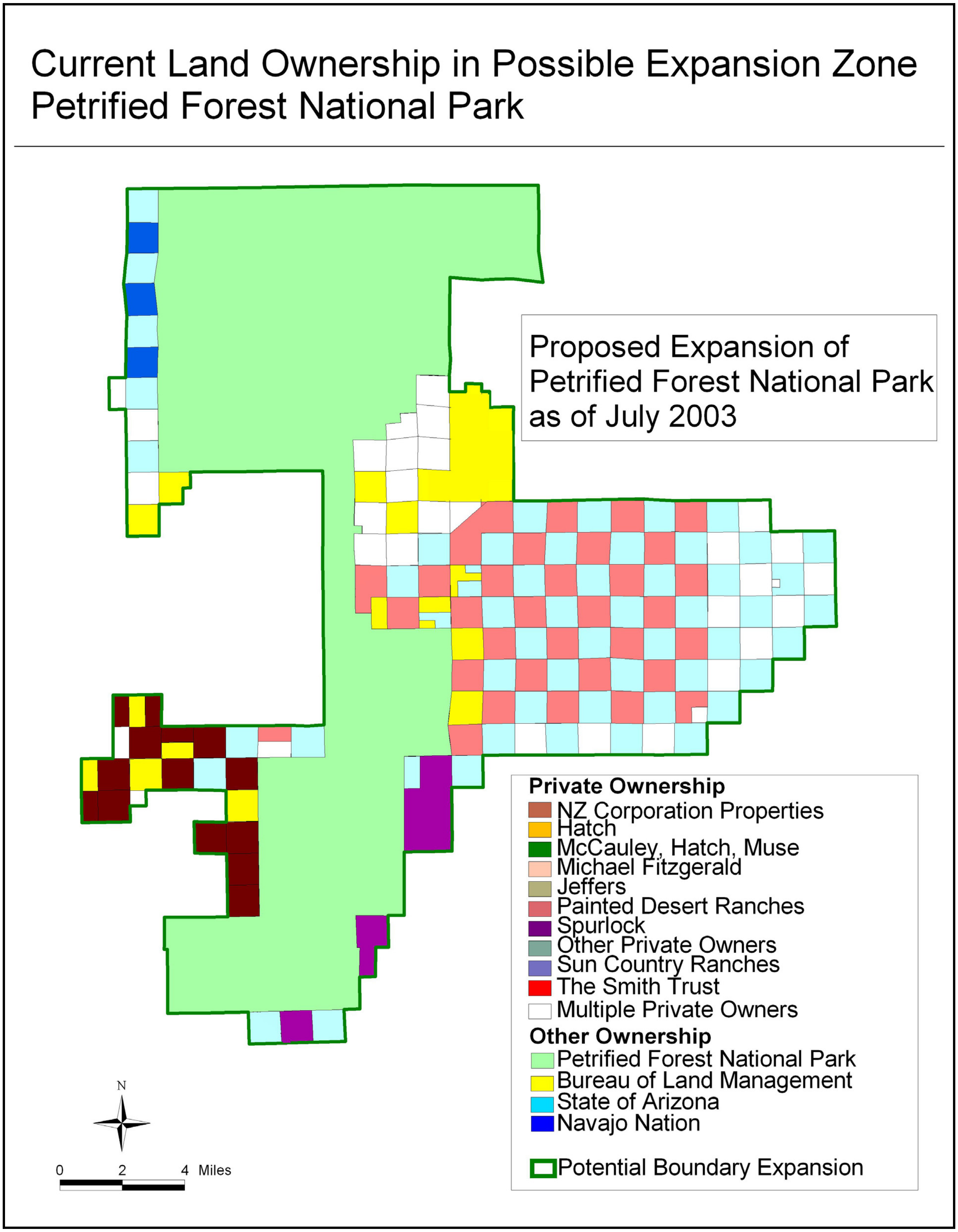


Figure 2. Current park boundary and proposed park expansion.

II. HYRDOLOGIC ENVIRONMENT

Description of the Physical Environment

Climate

Petrified Forest National Park is located in high desert, with a dry climate and average temperatures much lower than those of the low deserts to the south and west. The average elevation of the park is 5,600 ft above sea-level (National Park Service, 1991), with the highest elevations atop the Painted Desert mesas (the park's highest point is the top of Pilot Rock, elevation 6236 ft) and the lowest points along the Puerco River Valley (at elevations of approximately 5330 ft).

Mean monthly precipitation and average monthly temperature ranges are presented Figure 3. These data were obtained from the National Climatic Data Center web page for available data reported from 1931 – 2000 at the National Weather Service Cooperative Weather Station located within Petrified Forest National Park. (Data unavailable or corrupted for some months were removed for calculation purposes).

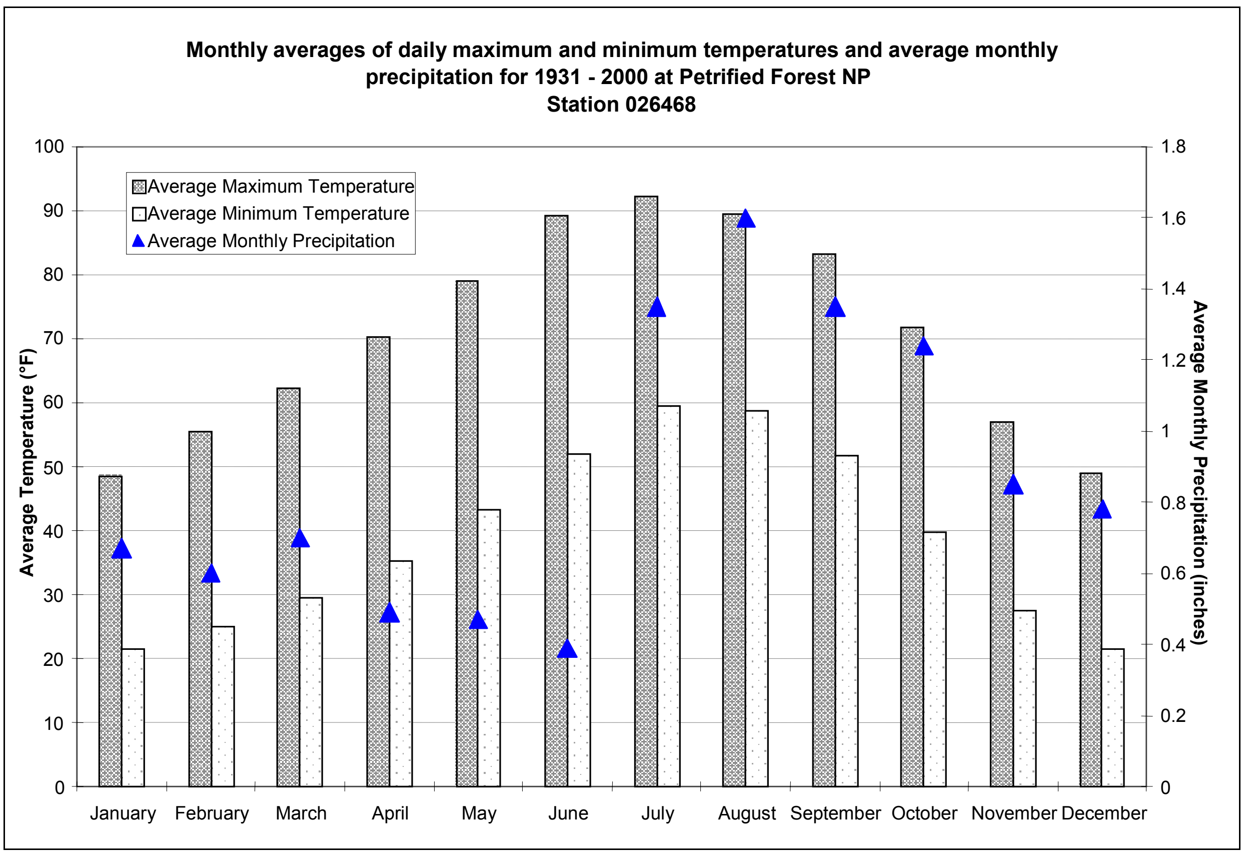


Figure 3. Monthly precipitation and temperatures at Petrified Forest National Park (1931-2000). [Source: National Weather Service Cooperative Weather Station – Petrified Forest National Park.]

The average annual precipitation calculated using the NWS data is 9.3 inches, with July-September generally being the wettest months and April – June generally being the driest months. The heavy summer precipitation in Petrified Forest National Park is typical of the Colorado Plateau. During the North American monsoon season, precipitation arrives as the product of afternoon thunderstorms. The start of the monsoon season varies annually and may vary from location to location within the Southwest. Normally, the monsoon lasts from early to mid-July until the middle of September (Figure 3). The duration of the North American Monsoon is determined by the position of the Bermuda subtropical anticyclone (Carleton, 1985, 1986, 1987; Carleton et al., 1990). Winter rains and snowmelt are responsible for inputs to streams and washes during the winter and spring months.

It has been asserted that there have been significant climatic changes in the Colorado Plateau during the twentieth century. Using precipitation records from multiple stations in the Colorado Plateau, Hereford (1989) found that there was a period of relative drying following 1940 both in the Little Colorado River basin and in the wider Southern Colorado Plateau.

Hereford argues that simultaneous channel aggradation in many streams throughout the Colorado Plateau points to a single cause (Hereford, 1989) and that the determining factor was a climate change resulting in reduced runoff and channel flows in small and intermediate-sized watersheds. Hereford (1989) reports an apparent reduction in the amount and frequency of rainfall in the period 1943-1979 when compared to the periods 1928-1942 and 1980-1985 although the reasons for these changes are difficult to establish because of the lack of pre-1945 cyclone data.

For additional discussion of the climatological factors influencing weather patterns, temperatures and precipitation in the southwest, the reader is referred to Sheppard et al., 1999.

Geology

Petrified Forest is primarily a geological park. The stunning vistas and barren “badlands” of the park are a result of the interaction between geology and climate. The paleontological resources, which the park was initially created to protect, are exposes from the substrate by rain- and wind-induced erosion in the park.

Consistent with the rest of the Puerco River Basin (Webb et al., 1987), the bedrock in the park is composed of gently northeast dipping Mesozoic sedimentary rocks. The interbedded shales and siltstones of the Chinle formation provide the components necessary for both the erosion-resistant sandstone caps of the cuestas and mesas and the highly erodable underlying shale and siltstones.

Triassic volcanism resulted in the deposition of the ash in the park that weathered to form the montmorillonite clay (also referred to as bentonite) found in the park today. The source zone for this material is believed to be the Mogollon Highlands to the south of the park (National Park Service, 1991). Volcanic ash may have been transported by the wind from volcanic fields as far to the West as Nevada (Harris, 1977). The deposited ash served as the source for the leached silica believed to be responsible for the petrifaction of the logs which are the park's main attraction.

The Triassic sediments were subsequently buried and then re-exposed during the past 35 million years of uplift and erosion (National Park Service, 1991). The oldest exposed formation is the park is the Moenkopi, deposited in the middle Triassic. The Moenkopi is overlain by the Chinle, the formation in which the fossils and petrified wood are located.

The Chinle Formation is composed of the Shinarump, the Lower and Upper Petrified Forest, and the Owl Rock Members. The Shinarump is a basal conglomerate, made up of Paleozoic clastic and igneous cobbles. The Petrified Forest Member is composed primarily of alluvial shales and siltstones (Harris, 1977). The colors of the Painted Desert are created by iron and manganese oxides contained in the Chinle Formation. The Pliocene Bidahochi Formation may be found on some mesa tops in the Painted Desert (National Park Service, 1991).

Uranium is found in sandstone deposits in both the Chinle and Moenkopi formations. In typical sandstone type uranium deposits, the uranium is emplaced by groundwater solutions with their origins in igneous rock or volcanic ash. Because a reducing environment is necessary for the precipitation of uranium-bearing minerals, it often occurs in the presence of organic material or iron sulfides (Christensen, 1979) such as the buried trees, ferns and fauna of the Petrified Forest Member.

Soils

The park soils are derived from the bedrock and are composed primarily of silts, clays, and sands derived from the Chinle formation. The soils are calcareous and moderately alkaline, pH 7.9 - 8.4. The most fertile soils within Petrified Forest National Park are generally found in the rolling grasslands, which are often located between mesas and badlands, as well as on a few of the mesa tops. These soils are composed of alluvial and wind-blown sands, making the soils quite permeable. The park's badland soils are composed of material derived from shales and have low permeabilities and high salt content (National Park Service, 1991).

Clayey soils are particularly inhospitable to vegetation because the capillary pressure, or tension with which soil water is bound to soil particles, is very high in soils with small average particle sizes. The capillary pressure must be overcome by the osmotic pressures in plant roots in order for plant roots to take up water. Water held at tension too high to be overcome by plants is effectively unavailable, and the amount of water available to plants in clayey soils is quite low. In an arid environment, the presence of clayey soils significantly limits the potential for the development of organic soils and vegetation.

The Federal Highway Administration site analysis of the Jim Camp Wash established that the sediments in the wash vary from a fine sandy loam to a silty clay loam. The deposits were deep and composed primarily of silts and sands deposited during flash flood events (Slettin, 2000). Soil survey data for those parts of the park located in Apache County are available in hard copy at the park and digitally. The digital data may be downloaded from the Ft. Worth Natural Resources Conservation Service web site (http://www.ncgc.nrcs.usda.gov/). Less detailed, 1:1,000,000 scale GIS data are available from the state of Arizona (http://www.land.state.az.us/). These data must be ordered, but can be obtained free of charge by government agencies.

Hydrologic Profile

Surface Water

Petrified Forest National Park straddles the boundaries of three USGS hydrologic catalog units (Figure 4). Most of the park is located within the Lower Puerco Watershed (USGS HUC 15020007), part of the larger Puerco River Watershed. The Puerco River, now named for its sediment-laden flow, was once called Tó Nízhóní or “beautiful water” by the Navajo (Wirt, 1994). The Upper Little Colorado River Watershed (USGS HUC 15020002) drains the southwest corner of the park. The northern boundary of the Upper Little Colorado River HUC cuts southeast across the park in the area of the Flattops. Leroux

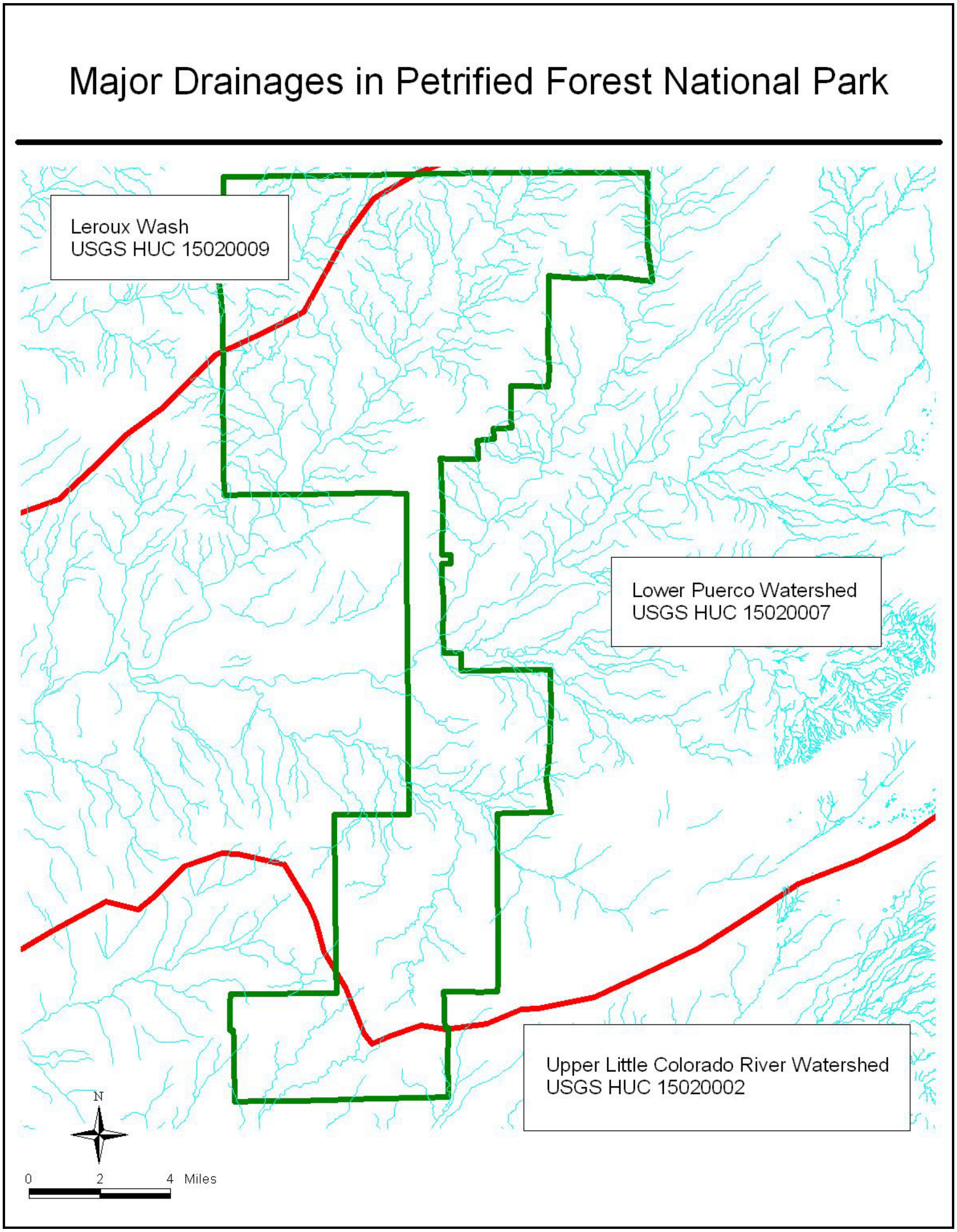
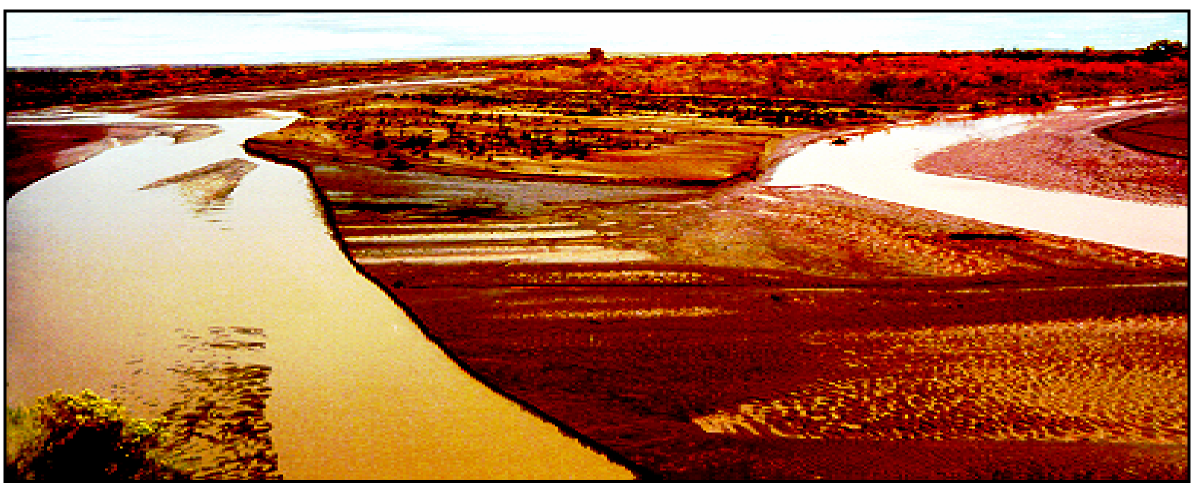


Figure 4. Drainages and hydrologic catalog units (HUCs) within Petrified Forest National Park.

a. Puerco River Bridge in 1932



b. Puerco River and Nine Mile Wash in 2001.

Photograph 1. Puerco River in Petrified Forest National Park (1932 and 2001).

Wash (USGS HUC 15020009) drains the extreme northwest corner of the park. The hydrologic boundary of this hydrologic unit is located within the park in the hills southeast of Digger Wash.

Streams within Petrified Forest National Park are ephemeral in nature and only flow in response to rain and snow melt in the spring, and flash-flooding during the summer monsoon rain season. The major surface water features include the Puerco River as well as Lithodendron, Dry, and Jim Camp washes. All drainages within Petrified Forest National Park ultimately flow into the Little Colorado River, a tributary of the Colorado River.

There are no USGS stream gages currently operating in the area of the park. Historic flow data can be gathered from two inactive gages that were located in and around the park (National Park Service, 1999). The two historical gages located in the park were USGS09396500 along the Puerco (1940-1949) and USGS09396400 along a tributary of Dead Wash (1963-1975) (National Park Service, 1999). The stream data may be retrieved at http://waterdata.usgs.gov/nwis-w/AZ/. More recent stream flow information must be inferred from a USGS stream gage located on the Puerco near Chambers, approximately 25 miles upstream from the eastern boundary of the park. The gage, USGS 09396100, near Chambers, records only flows exceeding 500 ft^3/s. Historical and real-time stream flow data demonstrating the episodic nature of flows in the Puerco are available at the Arizona USGS water resources web site.

Surface water within Petrified Forest National Park is also available seasonally in small pools (tinajas), springs / seeps, and abandoned stock impoundments, which are referred to locally as “tanks”. Since the amount of surface water within the park is limited, the availability and quality of water at the small pools and seeps take on additional significance, yet they are the most poorly characterized and understood water resources in Petrified Forest National Park. These waters serve as hatching areas for insects, amphibians and watering areas for larger animals. At Capitol Reef National Park, the tinajas have proved to be critical water supplies to several species of toads, frogs, bats and ungulates (Spence and Henderson, 1993).

Stratigraphy and morphology typically control the location of points at which groundwater “daylights” (i.e., reaches the ground surface from below ground) forming springs or seeps. On the mesas of Petrified Forest National Park, rainwater infiltrates permeable surface materials, often aeolian sands and soils and then the fracture systems in the eroding sandstone. When percolating rainwater encounters an unfractured rock layer of a much lower permeability, it travels horizontally, down-dip along the contact. If at some point the contact is exposed, for example along the vertical wall of mesa, the water daylights (Spence and Henderson, 1993). Within the park, the areal extent of beds supplying water to seeps and springs are limited and are therefore unlikely to produce large volumes of water (Aughenbaugh, 1970).

There are believed to be only three springs in the park. The 1957 Water Resources Report documents a flow from a spring on Blue Mesa that was sizable enough to be collected (Palmer, 1957). Active springs in both the Zuni Well and Agate Bridge areas were reported by Jones (1986). The presence of a spring along the mesa face at Agate Bridge was verified by park staff (C. Dorn, Petrified Forest National Park, personal communication, 2000).

Tinajas are rock depressions which are typically filled by rain or overland flow. They may be small and ephemeral or somewhat larger and perennial. While spring fed rock depressions are not technically “tinajas” the term is often is often applied to any water-filled rock depression within the park. Kokopelli or Celebration Man Tinaja, visited during November of 2000 following the second consecutive summer of regional drought conditions, provides a good example where water running off the top of the mesa contributes to the water in the pool, with some of the water remaining in the pool, even during extreme droughts. As petroglyphic evidence suggests that water may have been present in the pool in the distant past as well (C. Dorn, Petrified Forest National Park, personal communication, 2000), it is likely that the pool is at least partly supplied by groundwater.

The primary source of information regarding the location of the flowing and non-flowing waters within the park is the park-based field staff (rangers, interpreters, resource managers, maintenance employees, etc.). Park Resources Management staff have only recently begun to map the locations of tinajas, seeps and other hydrologic features. In order to understand the ecological significance of hydrologic features in the park, their density and geographic distribution must be understood.

Photograph 2. Kokopelli or Celebration Man Tinaja and associated petroglyph (2001).

A number of studies have been conducted on the tinajas of nearby Capitol Reef National Park in Utah. The studies may be of interest in that they have examined the change in the volume of tinajas in the water pocket fold during the course of a summer (Baron et al., 1998) and examine the effects of flooding and drying on biological diversity and community recovery. The Capitol Reef system, is however, very different from that at Petrified Forest in several important ways. The Waterpocket Fold system contains many tinajas and large rains may actually cause overflow from one tinaja to another. There are fewer tanks and tinajas at Petrified Forest and they are located remotely from one another. It is also likely that the Petrified Forest tinajas are located in more diverse geological settings than those at Capitol Reef, which are nearly all located in the Navajo Sandstone (Spence and Henderson, 1993).

Surface Water Quality

The pollution of surface waters and groundwaters by both point and non-point source pollution can impair the natural functioning of aquatic and terrestrial ecosystems and diminish the utility of park waters for visitor use and enjoyment. While surface water is scarce within Petrified Forest National Park, water quality has historically been a particular concern because until recently, shallow wells into the Puerco Alluvial Aquifer provided the drinking water supply for park visitors and staff. The shallow Puerco Alluvial Aquifer is recharged from the Puerco River, where heavy metals including lead and arsenic and radioactive species including uranium and radium 226 sometimes exceed US Environmental Protection Agency drinking water criteria (National Park Service, 1999). While the park's domestic water supply is currently provided by the Navajo Tribal Utility Authority (NTUA), the park's employees and visitors have depended on the alluvial aquifer for drinking water for more than half a century and still consider the alluvial aquifer a viable supply of potable water should there be a service disruption from the NTUA.

While existing surface water quality information is limited, the Arizona Department of Health Services conducted water quality monitoring from the Puerco River at the park road bridge in February and April of 1985 (Arizona Department of Health Services, 1986). A comparison of these data with US Environmental Protection Agency (EPA) published water-quality criteria (US Environmental Protection Agency, 1995) indicated that six groups of parameters exceeded EPA recommended standards at least once. Arsenic, copper, lead, and zinc exceeded their respective EPA standards for the protection of aquatic life, while arsenic, lead, radium 226, and uranium exceeded their respective EPA drinking water standards (National Park Service, 1999).

Arsenic concentrations (including dissolved and total) were measured four times within the park in the Puerco River at the park road bridge in 1985. Two samples, 460 micrograms per liter and 300 micrograms per liter, exceeded the drinking water standards of 10 micrograms per liter in February and April 1985, respectively (National Park Service, 1999). The highest concentration of 460 micrograms per liter also exceeded the acute freshwater criteria of 360 micrograms per liter.

Copper concentrations (dissolved and total) were also measured four times within the park in the Puerco River at the park road bridge in 1985. Two samples, 570 micrograms per liter and 240 micrograms per liter, exceeded the acute freshwater criteria of 18 micrograms per liter in February and April 1985, respectively (National Park Service, 1999).

Lead concentrations (dissolved and total) were also measured four times within the park in the Puerco River at the park road bridge in 1985. Two samples, 450 micrograms per liter and 190 micrograms per liter, exceeded the drinking water standards of 15 micrograms per liter and the acute freshwater criteria of 82 micrograms per liter in February and April 1985, respectively (National Park Service, 1999).

Radium 226 concentrations (dissolved and total) were also measured four times within the park in the Puerco River at the park road bridge in 1985. Two samples, 62 picocuries per liter and 14 picocuries per liter, exceeded the drinking water standards of 5 picocuries per liter in February and April 1985, respectively (National Park Service, 1999).

Uranium concentrations (dissolved and total) were also measured four times within the park in the Puerco River at the park road bridge in 1985. Uranium concentrations ranged from 60 micrograms per liter to 290 micrograms per liter, exceeding the drinking water standards of 20 micrograms per liter (National Park Service, 1999).

Zinc concentrations (dissolved and total) were also measured four times within the park in the Puerco River at the park road bridge in 1985. Two samples, 1800 micrograms per liter and 790 micrograms per liter, exceeded the acute freshwater standards of 120 micrograms per liter in February and April 1985, respectively (National Park Service, 1999).

While it is difficult to assess the source of these pollutants, natural and potential anthropogenic activities such as erosion, minerals extraction, wastewater discharges, ranching activities, stormwater runoff and atmospheric deposition are possibilities.

Potential sources of radioactive material in the Puerco River Basin include:

- naturally occurring erosion of radionuclide-bearing rocks and sediments in the watershed;
- long-term releases of radionuclides into the stream as waste products of uranium mine dewatering processes; and,
- a one-time catastrophic release of uranium tailings from an upstream impoundment.

The Puerco River originates within the Grants Mineral Belt in New Mexico where uranium ore is present in and around the source of the Puerco River. Sediments resulting from the natural erosion of uranium bearing rock have been washed into the Puerco River over the years. However, uranium mining in this region began in earnest in the 1950s and continued intermittently until the mid 1980s (Gray and Webb, 1991).

Little is known about the nature and volume of mining discharges coming from the Grants Mineral Belt during the 1950s (Webb et al., 1987). Beginning in the early 1960s, discharges from uranium mine dewatering activities were permitted to flow into Pipeline Arroyo and then into the Puerco River (Van Metre and Gray, 1992). Settling ponds and flocculents were used to treat process waters beginning in the 1970s, reducing the amount of sediment released to the system from dewatering. Mine dewatering ended in 1986 when activity ceased in the last active mine.

The largest release (by volume) of low-level radioactive material ever occurring in the United States occurred along Pipeline Arroyo (35 miles northeast of Gallup, NM) , a tributary of the Puerco River in 1979. On July 16, 1979 a tailings pond retention dam collapsed at the Church Rock Uranium Mill. The waste spilling from the tailings pond flowed along the streambed of the Puerco River until the flow dissipated due to streambed infiltration and evaporation near Chambers, Arizona (Weimer et al., 1981). The volume of the release was estimated to have been 94 million gallons of waste with a pH of less than 2 and a gross alpha particle activity of 128,000 PCi/L (Shuey, 1992).

As significant as this event was, Van Metre and Gray (1992) estimate that 380 times more uranium and 6 times more gross alpha activity were released from 1968 to 1986 due to dewatering activities than was released during the tailings pond failure. Overall, uranium mine dewatering is believed to have elevated dissolved gross alpha activities as far downstream as 200 km, including the reach of the Puerco River through Petrified Forest National Park (Van Metre and Gray, 1992).

In addition, the city of Gallup, New Mexico has discharged the outflow from its municipal sewage treatment facility into the Puerco River since 1958 (Shuey, 1992). The volume of the outflow was approximately 2.5 million gallons per day (gpd) in 1989 (Wirt et al., 1991). The reported average release is 2.8 million gallons per day, about 14.5% of which is diverted for municipal irrigation between April and October. During irrigation season, about 2.4 million gallons are released on a daily basis (R. Espinoza, City of Gallup (New Mexico), personal communication, December 2000). Under the current flow regime, output from the wastewater treatment facility provides a permanent flow downstream from the plant to the New Mexico/Arizona State line. A sewage line break at the wastewater treatment plant led to a 6.1 million gallon raw sewage discharge in 1988. A "greenish-colored sludge" was observed along a twelve-mile stretch of the river ending around Manuelito (Shuey, 1992). No data regarding sewage spills are available after 1990 (Shuey, 1992).

Groundwater

Petrified Forest National Park overlies two aquifers from which significant amounts of water can be withdrawn. The Puerco River Alluvial Aquifer is a narrow ribbon of alluvium associated with the Puerco River. The Coconino Regional Aquifer or C Aquifer includes the sequence of sedimentary rocks from the top of the Kaibab Formation through the upper part of the Supai Formation (Hart et al.,2002) It is named for the primary water-bearing rock unit of the aquifer, the Coconino Sandstone.

The Puerco River Alluvial Aquifer underlies the river and is recharged during periods of flow. The aquifer is composed of interbedded gravel, sand, silt and clay although the spatial variation in the composition and hydrologic properties of the aquifer are not well understood (Webb et al., 1987). The wells drilled into the Puerco alluvium have been relatively shallow. Puerco Well No. 1 was drilled in 1957 to a depth of 48 feet, with the depth to water being 10 feet. For modeling purposes, Van Metre and Gray (1992) estimated that the porosity of the Puerco River Alluvial Aquifer materials, which they defined as "predominantly medium-fine sand" to be about 30%. Although the stratigraphy of the alluvial aquifer is unknown, several wells have been drilled up to 200 ft deep without encountering bedrock (Webb et al., 1987).

The Coconino Regional Aquifer or C Aquifer is much deeper. The C Aquifer underlies much of north-eastern Arizona and northwestern New Mexico including Hubbel Trading Post National Monument and the Flagstaff Parks (Hart et al., 2002). There are two wells in the park that are completed in the C Aquifer. The Rainbow Forest Well is 980 feet deep and the Agate Bridge Well is 780 feet deep. The C Aquifer is confined in the area of the park and the groundwater gradient is to the northwest. Water from the Agate Bridge and Rainbow Forest wells is not used in the park because of its high dissolved solids concentrations.

The long-term impacts of ground water withdrawals from the C Aquifer by the Cholla Generating Station in Joseph City and the Coronado Generating Station in St. Johns are a concern of the National Park Service (B. Hansen, NPS Water Resources Division, personal communication, September, 2000).

There are three operational wells in the park, only one of which produce water suitable for domestic use. The Puerco No. 2 Well is the former source of park drinking water. It is completed in the Puerco River Alluvial Aquifer in Section 9, T18N.,R24E. Two additional wells completed in the C Aquifer are maintained, but unused. They are located at Agate Bridge and Rainbow Forest. All other wells in the park have been capped.

In 1959, Puerco Well No. 2 was constructed to replace a well drilled in 1934 which was abandoned when silt clogged the well and reduced production. Puerco Well No. 2 is connected to a concrete reservoir located at an elevation of 5916 ft. msl on Hill 5924 (BM) T19N R24E section 4 elevation 5322.5 ft msl). Puerco Well No. 2 is currently maintained and "exercised", but is not used as a water supply (C. Thomas, Petrified Forest National Park, personal communication, 2000). The well house is located on the north bank of the river, in clear sight of the bridge. Numerous water quality samples from the well show a consistent concentration of total dissolved solids around 950 mg/l. Although water from the Puerco No.2 Well meets primary drinking water standards, it is marginal being high in sodium and sulfate. Poor water quality and concerns about relying on a potentially contaminated water source caused the park to connect to the regional water supply system operated by the Navajo Tribal Utility Authority.

Other historic wells include the Zuni well which appears on the topographic map marking the location of an old oil prospecting well, which was drilled to a depth of 3000ft (Aughenbaugh, 1970). This well was later plugged and completed as a water well (Palmer, 1957). Other references to the Zuni water wells refer to a series of four production wells and six test wells that were located in Lithodendron Wash in section 5 T19N, R24E and section 32 T20N, R24E in the Painted Desert Section of the park (Palmer, 1957). They were believed to draw water from a lens in the Chinle formation, rather than from a regional aquifer (Palmer, 1957). Like the water produced in deep park wells, the Zuni wells water was highly mineralized (1680 mg/L TDS) (Aughenbaugh, 1970). The Zuni water wells were capped in 1968.

A well was drilled in the Rainbow Forest area in 1932-1933. It is completed in the Coconino Aquifer and never produced potable water. Saline waters are believed to be entering the well bore from the overlying Moenkopi formation (Palmer, 1957). In 1970, the location of the Rainbow Forest Well was unknown and it is believed to be capped and buried.

The current Rainbow Forest Well was drilled to a depth of 980 ft. in 1984 and is located in T17N R23E section 35. An analysis of pumped water in 1984 yielded a TDS concentration of 9,910 mg/L. The well is not pumped and there are no plans to use the well for anything other than monitoring water levels.

A private well completed in the Puerco alluvial aquifer is located inside the park, west of Newspaper Rock. It was accidentally drilled on park property and a special use permit was issued for its use for cattle watering (Permit No. 14-10-0333-1573) (Aughenbaugh, 1970). The well water was sampled as part of the alluvial aquifer analysis conducted by Webb and others in 1987. The well, (A-18-24)16bbb01, is referred to as both the Petrified Forest Windmill Well and the Pausel Well.

Monthly water level measurements at the Puerco Well No. 2 and Agate Bridge wells are made by the Resource Management staff. Water samples are collected from the Puerco Well No. 2 for chemical analysis quarterly. The water samples are shipped to the University of Virginia where pH, conductivity, alkalinity, and Ca^{2+}, Na^{+}, and Mg^{2+} concentrations are measured. Analysis of a sample from Agate Bridge Well yielded a TDS concentration of 19,800 mg/L shortly after the well was drilled in 1984.

Water Supply

Historically, the primary water-related concern in Petrified Forest National Park has been ensuring that the park has a water supply adequate in both quantity and quality to meet the needs of visitor services, fire suppression, and household needs of park and concession employees. Prior to 1997, water demand was met by a number of wells located inside the park. In 1997, the park began purchasing water from the Navajo Tribal Utility Authority (NTUA).

The development of the Navajo New Lands and the increasing number of residents dependent upon the NTUA system for drinking water pose the greatest risk to the purchase of Navajo water by the park.

Although the main Navajo and Hopi Reservation may dwarf the Navajo "New Lands" located north and east of the park, development in the New Lands may eventually determine how much water is available for visitor use in Petrified Forest National Park. The population shift may increase the historical number of residents in the Chambers and Sanders areas from several hundred to as high as 10,000 (Webb et al., 1987). The NTUA is under no obligation to continue supplying the park. Should it become disadvantageous for the NTUA to sell water to the park, the park would be compelled to revert to the use of Puerco Well No. 2 to meet park potable water needs.

Water Rights

Surface water rights in Arizona are allocated according to the Doctrine of Prior Appropriation. Under this doctrine, the party who first utilizes water for a beneficial use has a prior right to use, against all other appropriators – e.g., "first in time, first in right". The water must be put to beneficial use as defined by the State. In Arizona, beneficial uses include irrigation, domestic, stockwatering, municipal, commercial, industrial, mining, recreation, fish and wildlife, and other uses. An appropriative water right is a property right; under State law it can be bought, sold, and its place of use, purpose, and point of diversion can be changed without loss of priority provided there is no injury to the water rights of others.

In Arizona, the right to use groundwater is tied to property. Due to concerns about overproduction of groundwater, Arizona has curtailed the rights of property owners in certain areas to withdraw groundwater under Arizona's 1980 Groundwater Management Code. The restrictions apply only to lands within five regions, known as Active Management Areas (AMAs), with the highest groundwater consumption and largest populations. Groundwater withdrawal outside AMA's is unrestricted. Petrified Forest National Park is not located in or near any of the AMAs (Arizona Department of Water Resources, 2001) and permits are not required for groundwater withdrawals or use.

Federal reserved water rights arise from the purpose for the reservation of land by the federal government. When the government reserves land for a particular purpose it also reserves, by implication, enough water unappropriated at the time of the reservation as is necessary to accomplish the purposes for which Congress or the President authorized the land to be reserved, without regard to the limitations of State law. The rights vest as of the date of the reservation, whether or not the water is actually put to use, and are superior to the rights of those who commence the use of water after the reservation date. General basinwide adjudications are the means by which the federal government claims its reserved water rights. The McCarran Amendment (66 Stat. 560, 43 U.S.C. 666, June 10, 1952) provides the mechanism by which the United States, when properly joined, consents to be a defendant in an adjudication.

Once adjudicated by the State, the water rights of the United States, reserved and appropriated, fit into the State priority system along with those of all other appropriators. In general, when it is brought into a general adjudication, the United States is given its only opportunity to assert its claim to water rights. Unless legally absent from the proceedings, it is generally understood that failure to assert a claim to water rights in such a proceeding may result in forfeiture of these rights.

The Little Colorado River (LCR) adjudication began in 1978. In 1985, the United States Department of Justice, on behalf of the National Park Service, submitted a claim for federal reserved and appropriative water rights at Petrified Forest National Park (File No. 39-89222). Federal reserved water rights were claimed for water necessary to fulfill reservation purposes, including wilderness and administrative purposes. The National Park Service has also claimed appropriative rights for several wells on acquired lands. The NPS has signed five stipulations with major industrial users (Abitibi Consolidated Sales Corporation, Arizona Public Service, Salt River Project, and Tucson Electric Power Company) and the

City of Flagstaff to resolve water rights issues between the parties for Petrified Forest National Park. On July 16, 2002, the LCR Decree Court confirmed the binding effect of the five stipulations but is yet to decree the rights.

Additional information on the Little Colorado River Adjudication may be obtained at the Arizona Judicial Branch General Stream Adjudication web page (http://www.supreme.state.az.us/wm/default.htm).

Streambed Ownership

A second Arizona adjudication involving Petrified Forest National Park is underway. The State is seeking to establish the navigability or non-navigability of rivers in Arizona. (ARS title 37-1129.07), significant because the streambeds of all streams navigable at the time of Arizona statehood are public lands under Arizona State law. In 1995, the park responded to information requests regarding the historic flows and uses of the Puerco, explaining that the ephemeral nature of flows, both current and historic precluded the commercial or navigational use of the Puerco. Subsequently, the state has determined that the Puerco River is not navigable and has relinquished all claims to ownership of the streambed. More information about the stream navigability adjudications may be obtained at the Arizona Navigable Stream Adjudication Commission web page, http://aspin.asu.edu/ansac.

Wetlands

While all streams in Petrified Forest National Park are ephemeral, riparian zones along these stream corridors support a riparian vegetation ranging from “none” to zones dominated by tamarisk, to well developed cottonwood/willow communities. The condition of the riparian communities along the larger streams, such as the Puerco River is thought to be poor, with large areas dominated by tamarisk and little cottonwood production. However, there is no current information on why different streams support different riparian communities .

A research proposal has recently been funded which will allow for researchers from Colorado State University to begin to characterize the riparian community potential of the streams within Petrified Forest National Park, based upon their physical environment. Information form this study will be used to identify areas where tamarisk control and riparian restoration efforts could result in each site returning to its natural, potential biological community. It is anticipated that this project will lead to the development of a Riparian Area Resource Management Plan, including a Tamarisk Integrated Pest Management Plan and Environmental Assessment (Dr. David Cooper, Colorado State University, PMIS project proposal #85644, 2002).

Floodplains

In prior years, major flooding events have occurred along the Jim Camp Wash that passes close to the Rainbow Forest Visitor Center area, park housing and the concessions snack bar and gift shop. Until recently, the bridge across Jim Camp Wash consisted of a seven-cell box culvert which crossed the wash at an acutely skewed angle. The geometry of the bridge produced a backwater under high flow conditions, elevating water levels upstream of the bridge. Floating debris, such as brush, became entrapped in the bridge, leading to further restriction in under-bridge flow and increasing the incidence of road overtopping and flooding upstream from the bridge (Keeley, 1999).

The hydraulic problems caused by the bridge across Jim Camp Wash have been recognized for some time (Smillie, 1989; Petrified Forest National Park, 2001). In 2002, the box culvert-style bridge over Jim Camp

Wash was replaced with a new pier-mounted bridge with an elevated deck. While yet “untested” by a major storm event, Federal Highways Administration modeling efforts indicate that the new bridge should alleviate flooding in the Giant Logs area and that the bridge will not be overtopped even at flows associated with the 500 hundred-year flood event.

Only limited information regarding floodplains is available for other areas within Petrified Forest National Park. Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) exist for portions of the park located in Apache County (Community No. 040001 Panel numbers 1575, 1675, 1775 and 1875) and Navajo County (Community No. 040066 1625 B and 1875 B). These Flood Insurance Rate Maps include limited 100-year flood frequency information derived in the early 1980s for Jim Camp Wash, Cottonwood Wash, and portions of Digger and Lithodendron washes (FEMA, 2000).

In addition, flood frequency data are available Dead Wash from the Arizona Department of Transportation (ADOT) which has responsibility for the design of the I-40 overpasses in the area of the park. Hydraulic modeling of these data, conducted in accordance with standard procedures in the ADOT Highway Drainage Design Manual (Arizona Department of Transportation, 1994) indicate the 50 year flood in Dead Wash would have a flow of approximately 9150 cfs while the 100 year flood in Dead Wash would have a flow of approximately 12400 cfs.

Photograph 3. New bridge over Jim Camp Wash.

III. SIGNFICANT WATER-RELATED ISSUES

Adequacy of Baseline Water Quality Inventory and Monitoring Information

In 1999, the National Park Service completed a Baseline Water Quality Data Inventory and Analysis for Petrified Forest National Park (National Park Service, 1999). As part of this analysis, the National Park Service conducted an Inventory Data Evaluation and Analysis (IDEA) for the park in order to determine what NPS Servicewide Inventory and Monitoring Program "Level 1" water quality parameters have been measured within the study area.

The IDEA conducted for Petrified Forest National Park indicated that very limited data exist for eight of the 13 Level I parameter groups within the study area. No data have been reported to STORET for the flow, nitrate/nitrogen, phosphate/phosphorus, chlorophyll or bacteria parameter groups. For the eight parameter groups with data (alkalinity, pH, conductivity, dissolved oxygen, water temperature, clarity/turbidity, sulfates/Total Dissolved Solids/Hardness, and toxic elements parameter groups), the observations recorded were for only one site (Puerco River at Park Bridge) and for only two sampling dates in 1985. Furthermore, the observations recorded in 1985 included only six (metals only) of the 126 U.S. Environmental Protection Agency priority toxic pollutants (National Park Service, 1999). No water quality data are available for other washes within the park. However, it is likely that those washes cutting through radionuclide-bearing layers of the Chinle Formation may also contain some background levels of radiation.

Some inferences about the quality of water passing through the park in the Puerco River wash can be drawn from data obtained at the USGS gaging station at Chambers, AZ. Data are available between 1979 and 1985 show that the measured gross alpha values varied from 12 to 11,200 pCi/L. Dissolved alpha activities ranged from <3 to 320 pCi/L. Uranium, chloride and sulfate concentrations rose in response to the tailings dam collapse, but fell off and remained consistently low for the last five years of the sampling period (Webb et al., 1987).

Based upon the data inventories contained within this report (National Park Service, 1999), a shortage of observations exists for all surface water quality parameters within the study area. Due to the inadequacy of existing water quality inventory data in meeting park natural resource protection needs, the NPS Southern Colorado Plateau Vital Signs Monitoring Network (which includes Petrified Forest National Park) is scheduled to receive funding to initiate Level I water quality inventories in 2003. Results from these Level I water quality inventories are expected to be available in 2004 (G. Rosenlieb, National Park Service Water Resources Division, personal communication, 2002).

Radionuclide Contamination of Park Waters

Measured concentrations of radionuclides in the Puerco River are influenced by its source including both the natural erosion of uranium-bearing rock as well as past mining-related activities. Radionuclides can be transported into and through the system dissolved in the water, bound to filterable particles, or bound to colloids. The phase and composition of the radionuclides entering the Puerco River is a function of their origin.

Natural eroding radionuclide-bearing rocks are more likely to contribute sediment-bound radionuclides, than would settling pond waste. The highly variable areal distribution of precipitation in Arizona determines which tributaries contribute flow to the main Puerco River during a storm event. Sediments are known to be key transporters of radionuclides and other contaminants through the Puerco River Basin.

Heavy sediment loads are common for Puerco flows exceeding 3000 cfs (Webb et al., 1987). Such flows are highly episodic but are not rare, especially in the summer. Suspended particle-bound radionuclides may be transported some distance downstream from their origin and deposited in the riverbed. Deposited particles may be resuspended during subsequent storm events and transported further downstream (Webb et al., 1987), or they may be buried by subsequent erosion events until exposed by erosion at some later time. Particle-bound radionuclides may ultimately be transported out of the system in the sediment load of the stream. There is also inter-tributary variation in the amount of exposed radionuclide-bearing strata subject to erosion, meaning that the volume of radioactive material entering the Puerco varies from storm to storm depending on the contributing streams. The amount of uranium-bearing rock subject to erosion also varies temporally in each tributary (Gray and Webb, 1991).

During the period of uranium mining dewatering effluent and other treated uranium process waters were treated in settling ponds and contained limited amounts of radionuclides in the suspended phase. Van Metre and Gray confirmed the influence of radionuclide origin on composition in their 1992 study of dewatering effluent impacts on the Puerco River. In a stretch of the Puerco River upstream from the Gallup municipal Wastewater Treatment facility, they observed dissolved gross alpha, gross beta, uranium and radium activities declined after the cessation of mining activities. No statistical change, however, was observed for suspended phase radiation or in dissolved molybdenum or selenium (Van Metre and Gray, 1992). Studies in other systems have shown selenium, molybdenum and uranium comprise a larger fraction of the total concentration of released radionuclides in mining process waters than would be found in runoff (Van Metre and Gray, 1992).

Dissolved and colloidal-phase radionuclides may be removed from the system with the river water assuming that flow volumes are large enough that the river is flowing downstream from the park. Dissolved-phase radionuclides may be removed from solution by several particle-related processes. Radionuclides may bind to the surface of clays and other sediment grains. Under some circumstances, radionuclides may precipitate or co-precipitate, substituting for similarly shaped elements in the formation of minerals. The colloids to which radionuclides are bound may aggregate and form particles large enough to settle or be filtered, in which case they behave as suspended sediment-bound radionuclides. Dissolved or colloidal phase radionuclides are more likely to infiltrate the alluvial aquifer than suspended phase radionuclides.

Radionuclides, both dissolved and sediment-bound phase, may be taken up by biologic material, both plants and animals (US Geological Survey, 1987). A New Mexico Environmental Improvement Division study found that stock grazing in an area near the spill in the early 1980s showed elevated levels of uranium in their tissues (Millard et al., 1983, 1984). Webb et al. (1987) and others (US Geological Survey, 1987) found no significant uptake of radionuclides by perennial grasses and the biota are not believed to be responsible for any significant reduction in the amount of radionuclides in the system.

A threat can also be posed by blowing river sediment-bound radionuclides that might be inhaled or ingested by humans working in the streambed area. The USGS has, in fact, recommended the use of dust masks by those working in the area of the riverbed under no-flow conditions (Wirt, 1994). Ketterer's more recent work, however, indicated that radiation levels in the Puerco River surface sediment within the park have returned to levels considered "background" (2-3 ppb) and that sediments in the Puerco pose no greater threat than those of any of the other washes in the park (M. Ketterer, Northern Arizona University, personal communication, 2001).

The water in the Puerco No. 2 well, has to date, been unaffected by anthropogenic releases of radionuclides upstream of the park. However, the USGS has recommended continuing intermittent sampling of the well water to establish that no significant water quality changes have taken place.

Erosional Impacts

Erosion, both wind and water driven, is a threat to the park's paleontological and cultural resources. Fossil remains and petrified wood are themselves subject to the destructive effects of erosion once exposed. Unexposed resources, both archeological and paleontological, are often better protected from chemical and physical erosion as well as from theft.

While erosion poses a risk to the park's paleontological and cultural resources, it is also the process responsible for the fantastic badland landforms of the Painted Desert and the Teepees. Badlands are formed where rapid soil erosion rates and/or unsuitable soil types prohibit the establishment of vegetation that might stabilize the soils and help to inhibit erosion (Mears, 1963). There is little organic material in the park's badland soils, and rains are both rare and intense, further limiting the ability of the vegetation to establish itself and stabilize slopes. The abundance of volcanically-derived bentonite, an expanding clay that undergoes dramatic volumetric changes, in park soils makes slopes less stable than they might be otherwise.

The park's mesas, too, are erosional landforms. More erosion-resistant sandstone caprocks protect the underlying shales and siltstone. When the capstone is completely removed, teepees or pinnacles form from the remaining material (Harris, 1977). During a runoff event, the water flowing over the eroding siltstone surfaces runs through and further incises "shoestring" rills. Further discussion of badland landforms and references to other materials on the topic is found in Mears (1963).

During the 1980s, an earth flow led to the closure of a trail and threatened Newspaper Rock, an important petroglyph resource (Haiges, 1995). In the Newspaper Rock case, precipitation infiltrated the highly permeable windblown deposits located on top of the mesas, percolating through a fracture system to sandstone-shale contact where the water flowed laterally until reaching the mesa wall. The flow from the spring and increased precipitation were significant enough to undermine the side of the mesa.

In the mid 1950s, Park Paleontologist Edwin Colbert placed a series of stakes in the Blue Forest (later renamed Blue Mesa) area in order to measure erosion (Colbert, 1956). The stakes were arranged at a series of locations along a slope and an analysis of data a decade later (Colbert, 1966) indicated that erosion occurred up to a maximum of ¼ inch per year and that the rate of erosion was generally related to the degree of the slope. There were, however, some sites at which the effect of local topographical features outweighed the effect of the site slope (Colbert, 1966).

Park staffing levels and the size of the park are such that many areas of the park cannot be regularly patrolled to discover all the effects of erosion. The park policy on uncovered archeological resources (e.g. charcoal, ash, fire rocks, building materials, etc.), excluding human remains, is to allow them to erode naturally, although in the case of standing structures some form of stabilization may be considered (B. Parker, Petrified Forest National Park, personal communication, 2002). Human remains uncovered by erosion are treated in accordance with the legal mandates required by the Native American Graves Protection and Repatriation Act (PL 101-661) (B. Parker, Petrified Forest National Park, personal communication, 2002).

Paleontological resources, including fossil bones of prehistoric animals, remnants of plants, and preserved tracks or trails of prehistoric animals, differ greatly in their susceptibility to erosion and are preserved differently. Fossil wood consists almost entirely of silica and therefore is more resistant to erosion than even the surrounding rock. Therefore, it is allowed to erode naturally and is only protected against theft.

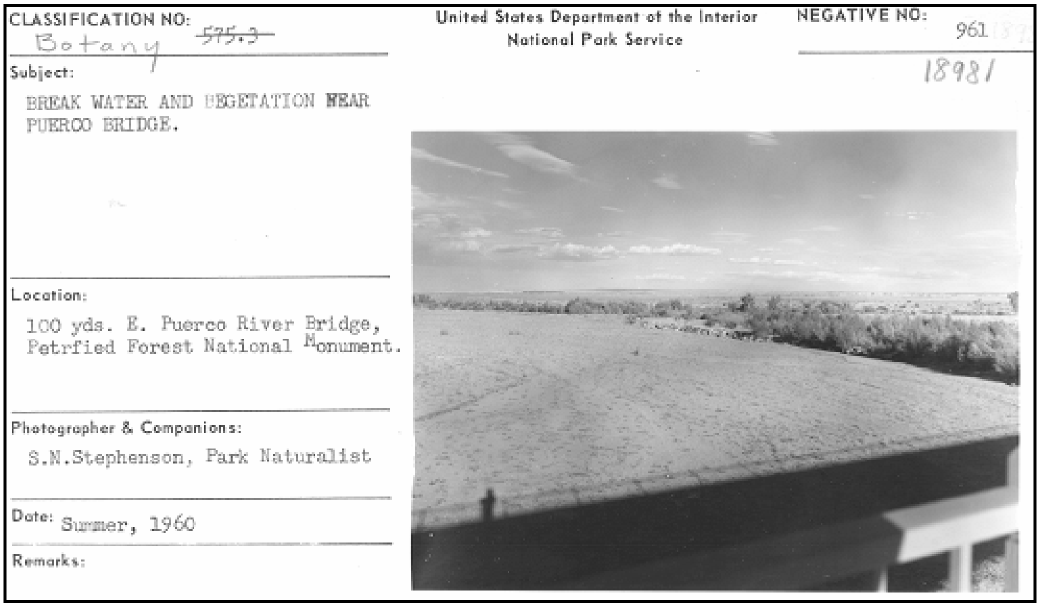
Fossil leaves occur in specific geological layers. Although these layers are subject to erosion, it is slow enough not to be a potential threat. Fossil tracks and burrows (trace fossils) always occur in resistant sandstones and are not readily destroyed by erosion. If this type of fossil is threatened it will be collected and curated into the museum collection to ensure its preservation. However, many trackways including those of dinosaurs can be exposed for very long periods of time with no adverse impact (B. Parker, Petrified Forest National Park, personal communication, 2002).

The fossilized bones of dinosaurs and other prehistoric animals are extremely fragile and very susceptible to erosion. Upon exposure to the elements, these resources will be quickly and completely destroyed. It is the current practice of the park to monitor sites where bones occur and to excavate any threatened significant fossil resources, and place them in the museum collections for preservation (B. Parker, Petrified Forest National Park, personal communication, 2002).

In cooperation with the Cooperative Ecosystem Studies Unit at the University of Arizona (CESU / UA), an erosion prediction model was developed by members of the University of Arizona Advanced Resources Technology Program (ART), a division of School of Renewable Natural Resources (http://www.srnr.arizona.edu/ART/publications/pfa_pap/index.html). The objective of this research was to integrate the park's geo-spatial resources protection data with predicted erosion rates to maximize the effectiveness of park resource protection efforts. The study group from the ART predicted the regions in the park subject to the greatest amount of erosion using the universal soil loss equation. Input values were obtained using GIS-calculated slope information and precipitation and soil records. Areas with both high predicted-erosion rates and high resource site density were identified for more intense patrols. The model, however, has not proved to be as effective in predicting the exposure of previously covered resources as was initially hoped.

Exotic Species- Tamarisk/Salt Cedar

The invasion of the non-native tamarisk or salt cedar (*Tamarix* spp.) is an issue of continuing concern for land managers in the American West and Petrified Forest National Park has not been spared. Introduced from the Mediterranean and Asia for slope stabilization and ornamental use, the various species of the genus *Tamarix* have spread rapidly and competed successfully with native riparian trees, primarily members of the cottonwood and willow genera, *Populus* and *Salix*, (McCown, 2000). In his report on the Petrified Forest National Park Tamarisk Control Program 1987-1990, Bowman carefully details a number of historic letters and reports located in the park files, which cover the initial appearance and subsequent expansion of tamarisk stands in the park. The first report of tamarisk in the park dates to 1937 and is consistent with tree-ring dating in Dry Wash in which the oldest tree was determined to have sprouted in 1940 (Bowman, 1991). In 1991, Bowman reported that there were some tamarisk in every park wash, with the highest concentrations of trees being located near the confluence of the Puerco River and Nine Mile Wash. As seen in the 1960 photograph (Photograph 4) at the aforementioned confluence, the tamarisk was in evidence primarily along the river's east bank, not the mid stream or confluence bars. Observations made of the same location in 2001 found extensive tamarisk on the bars separating Nine Mile Wash and the Puerco River, although removal efforts, recent riverbank fires, and the cottonwood and willow restoration efforts would have confounded the observations.


CLASSIFICATION NO: Botany ~~575.3~~
United States Department of the Interior
National Park Service
NEGATIVE NO: 961
18981
Subject:
BREAK WATER AND VEGETATION NEAR PUERCO BRIDGE.
Location:
100 yds. E. Puerco River Bridge, Petrfied Forest National Monument.
Photographer & Companions:
S.N.Stephenson, Park Naturalist
Date: Summer, 1960
Remarks:

Photograph 4. Photograph of vegetation near the Puerco River Bridge in 1960.

The ecosystem threats actually posed by the trees are the subject of some debate. Tamarisk trees are particularly resistant to the harsh conditions of the west: drought, saline soils and saline waters. They reproduce very effectively, creating some 500,000 wind-dispersed seeds annually (McCown, 2000). They also appear to be more resistant to intermediate length periods of root inundation and flood removal than are the competitor cottonwood and willow trees, and therefore able to germinate in areas of the streambed where the cottonwood and willow cannot. Due to its successful colonization and stabilization of bars and islands, it is asserted that tamarisk may have been an active agent in significant morphological changes occurring in southwest streams this century (Graf, 1978). The bed and bank stabilization may restrict water flow and lead to increased overbank flooding frequencies by reducing the capacity of streams to adjust to changes in flow (Graf, 1978). Stream aggradation, the restriction of stream channels and the explosion of the tamarisk population have occurred contemporaneously and the confounding factors make the role of the tamarisk in morphological changes difficult to isolate.

In a detailed study of changes in stream morphology in the Little Colorado River Basin, Hereford (1989) argues that sedimentological, morphological and photographic evidence argue for significant changes in stream appearance this century. The Little Colorado was a “broad, sandy and unvegetated” channel. In the late 1930s, the channel began to narrow and become occupied with vegetation. In addition to the incursion of salt cedar, Hereford (1989) cites an alteration in climate which led to higher temperatures, and reduced precipitation and stream flow. Additional National Park Service studies have found that similar processes were occurring in other Colorado Plateau rivers, including the Chaco, the Green and the Colorado at the same time. It is not unreasonable to suspect that similar forces should have been at work along tributaries of the Little Colorado River, 30 miles to the north.

The tamarisks are also less appealing as habitat for insects and birds that are critical to the biodiversity of arid land riparian areas (McCown, 2000). The elimination of native trees from park riparian areas would signal the loss of additional species as well. Mark DePoy, a former Natural Resources Specialist at Petrified Forest National Park, referring to uncited park mammalian surveys, wrote in a 1997 grant proposal, that the presence of tamarisk was a contributing factor to the reduced riparian area carrying capacity, which is only 30% of the historical value. The tamarisk secretes salt, which enters the surrounding soil and water, creating an environment that is more hostile to other species than it would otherwise have been.

The tamarisk removes soil water by evapotranspiration (perhaps as much as 200 gallons/day (De Poy, 1996), interfering with the ability of native species to obtain water. There has been no known case in Petrified Forest in which a reduction in the height of the local water table has been linked to tamarisk (Bowman, 1991).

Tamarisk removal is not entirely without potential ecological consequences. The trees have been in some areas of the park for over 60 years. A few species, most notably the Southwestern Willow Flycatcher, and others listed by the U.S. Fish and Wildlife Service as threatened or endangered use the trees as habitat, and might be harmed by the elimination of the tamarisk (McCown, 2000).

Despite the ambiguity of some of the evidence, tamarisk is unquestionably an invasive non-native species. In keeping with the Park Service's mission, the tamarisk should be controlled in order to minimize the impact it has on the native species that the NPS is obligated to protect.

Historic evidence from the Puerco River tells much the same story as the photographs used in Graf's 1978 study. Photos taken of the Puerco riverbed in the 1930s show a broad, sandy riparian corridor essentially swept free of vegetation (P. Thompson, Petrified Forest National Park, personal communication, 2000). Today, the bed of the Puerco is covered with sandbars and tamarisks are widely dispersed both along the bed and banks of the river. The spread of tamarisk in the park and early Park Service efforts to stem the expansion of tamarisk stands is documented in reports and letters in the park files (Bowman, 1991).

In 1968 and 1969 the park tamarisk eradication efforts included the herbicide spraying, using Emulsamine Brush Killer, a mixture of 2,4-D and 2,4,5-T, in riparian areas in the Painted Desert. The amount of pesticide applied is unknown. At least 2034 individual tamarisk plants were reported to have been treated (Bowman, 1991). Additional eradication efforts were made between 1978 and 1980 in a branch of the Jim Camp Wash using several methods including mechanical removal, cutting and cutting with herbicide treatment. The herbicides applied were Garlon 3A and 4. Another series of eradication attempts were made between 1987 and 1990 with a combination of cutting, and cutting and treating. The study also indicated that the removal of 1-2 year-old tamarisk shoots had an effective kill rate of 99%, was cost efficient, and eliminated the risks associated with the application of herbicides (Bowman, 1991).

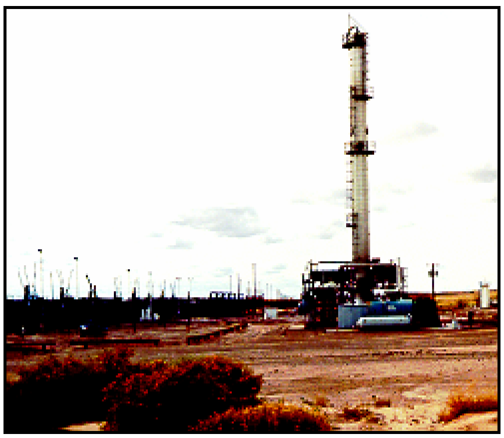
In 1996, the park submitted a proposal to the NPS Water Resources Division requesting funding to support a tamarisk suppression / riparian restoration project to occur along the Puerco River corridor (Figure 10). The project included funding for assistance by the tamarisk eradication crew out of Glen Canyon National Recreation Area. Approximately half of the area proposed for eradication was to be replanted with coyote willow and cottonwood. Four hundred acres were slated for tamarisk removal. Eradication work was conducted by the Lake Mead Exotic Plant Management Team (EPMT) and the support stakes for the replanted willows and cottonwoods that still stand in the sand bars of the Puerco near the bridge testify to the park's attempts to encourage the establishment of native vegetation in the place of the tamarisks in elevated areas of the stream channel. As the photos clearly indicate, very few of those trees became successfully established, but the extent to which various elements of the project plan were completed is still unclear.

Photograph 5. Tamarisk restoration effort at Petrified Forest National Park (2001).

Ferrellgas Petroleum Storage at Adamana

Ferrellgas, Inc. operates a liquefied petroleum gas (LPG) storage terminal in the old railroad town of Adamana. Adamana is located approximately 0.8 miles west of the park boundary at the Rio Puerco. The facility stores LPG in underground caverns in the Supai Formation. Ferrellgas has obtained an ADEQ Aquifer Protection Permit for the operation of four surface brine impoundments, twelve injection wells and sub-surface storage caverns. The lined brine impoundments, (two of which are clearly visible in the USGS aerial photograph of the Ferrellgas facility (1996)) are located a quarter of a mile north of the main well field facility. The first impoundments were installed prior to 1980. According to the Aquifer Protection Permit (No. P-102338) construction on the third impoundment was completed in 1995 and the fourth impoundment was to have been constructed in 1998. The brine is used to displace the LPG from the caverns in the Supai Formation where it is stored. (The Supai contains evaporite beds in which the storage caverns are located. Brine is used, instead of water, to displace the LPG to prevent further dissolution of the confining materials.) As the petroleum is typically drawn down during the winter and stored during the warmer months, the largest volumes of brine will be present in the impoundments in the early fall. Less brine will be stored at the surface during the winter and spring. The combined storage capacity of the brine impoundments is approximately 80 million gallons. It would appear, based on the draft aquifer protection permit, that the maximum elevation of the brine in pond three will be approximately 5426 ft. MSL.

a.


b.


c.

Photograph 6. Ferrellgas Adamana LPG Underground Storage Terminal (2001). (a) View Southwest of rail loading terminal, Puerco River approximately one mile in distance; (b) View West of rail loading terminal from access road; (c) View West of one lined brine pond, north of rail loading facility.

At the request of the park, the NPS Water Resources Division, reviewed the potential hydrological impacts of the gas storage operations and brine ponds at the Adamana Ferrellgas facility. They found that the general hydrologic gradient of the area was such that only unusual local surface features such as erosive surfaces would allow for flow of brine into the park in the event of an impoundment dike failure. Moreover, the NPS Water Resources Division concluded that storage in the Supai, some 1000 ft. below the surface and isolated from the Puerco alluvial aquifer from which the park's well draws water, by the impermeable Moenkopi and Chinle formations, also posed no known threat to water quality in the park (Werrill, 1994). The aquifer protection permit (APP No. P-102338) states that the brine ponds are located one mile north of the Puerco River 100 year flood plain of the Puerco River (Arizona Department of Environmental Quality, 1998). In addition, the NPS Geological Resources Division did an evaluation of the Ferrell Gas Facility and found that there were no additional significant hazards to park resources posed by the plant.

Mine and Landfill Reclamation Requirements

Petrified Forest National Park contains a number of borrow pits. Rock material was removed from the park for use in nearby roadbed construction. The park has been working to remove the material with which the borrow pits were filled, principally scrap metal and railroad ties (P. Thompson, Petrified Forest National Park, personal communication, 2000). The maps compiled as part of the Baseline Water Quality Data Inventory and Analysis show numerous mines, particularly in the Navajo area (National Park Service, 2000). The type of mine is unknown, but there are abandoned uranium mines regionally. The mines closest to the park are located downstream from the park and would therefore not pose a direct threat to park waterways. However, windblown distribution and deposition of contaminated dust surrounding mine sites could become involved in surface water even upstream of a mine site.

Other former waste disposal sites within the park pose a more significant threat to park surface and groundwater quality. Former landfills, in which household waste from park and concession housing and C.C.C. camps were dumped, are located along cut-banks. In addition to more benign materials, these sites could contain hazardous materials such as batteries. Permission has been obtained from the park archeologist to remove batteries and other patently dangerous material. Other items must be reviewed on a case by case basis (C. Dorn, Petrified Forest National Park, personal communication, 2000).

Trespass Cattle

Cattle entering the park in the washes compact the ground, disturbing the vegetation and other fauna (including nesting songbirds), and carrying and dispersing invasive flora seeds into and within the park. Cattle foraging inside the park also preferentially graze the more appetizing native cottonwood and willow species, further suppressing the growth of these more desirable species (DePoy, 1996). Trespass cattle (i.e. cattle belonging to adjacent landholders) wander onto parkland and must be routinely rounded up and driven outside of the park boundary (C. Dorn, Petrified Forest National Park, personal communication, 2000).

The construction of a boundary fence around the park was not completed until 1962-1963. Fences were not installed across Dead Wash or the Puerco River at the park boundary at that time, but were installed in 1982. Cross-wash fencing has a short life span in the park where flash floods are common occurrences. During the summer, a fence may last as little as two or three weeks before it is swept away by a flood. Normal flows in the washes also can remove portions of fencing because of cumulative floating debris damage to the wire strands and fence posts. There is currently no fence along the park boundary across the Rio Puerco streambed (W. Grether, Petrified Forest National Park, personal communication, 2000).

Issues Associated with Park Expansion

Expanding the park's boundaries as proposed in the General Management Plan (National Park Service, 1991) will extend the riparian corridor along the Puerco River under the jurisdiction of the park. As described earlier, the Puerco River passes through the neck of the park at its narrowest point. Although the addition of land along the eastern boundary of the park would create an ecological buffer zone for the stretch of the Puerco River within the current boundaries, it would also increase the area in the park where tamarisk pose a threat to native species. The land to be annexed belongs to the State of Arizona or private landholders (Figure 2). It has not been subject to the intensive tamarisk suppression efforts that have gone on within the park. The land has also been grazed and may be somewhat more prone to erosion than soils within the park which support undisturbed vegetation communities.

The inclusion of new lands in the park will significantly increase the data that remain to be gathered. As with areas, already included in the park, the locations of hydrological features and hazardous material threats in park additions will need to be identified and mapped.

Of the 97,800 acres in the proposed park expansion, only approximately 9600 acres were under the jurisdiction of the BLM prior to attempts by the various state and federal agencies to consolidate their holdings. It is therefore unlikely that there would be any new reserved water rights associated with the property that may be acquired. The park would be able to withdraw water from wells located in the expansion, provided that the wells were constructed to code and registered.

The proposed additions will add several manmade stock tanks to the park's holdings. Within the park's current boundaries, the question of tank management is moot, as the remaining anthropogenic tanks are leaking and do not retain water for long. With the acquisition of functional impoundments, park managers must consider whether the maintenance of the tanks is desirable and consistent with the park's natural resource management goals. Water-related features within proposed park addition areas are presented in Table 1.

Parcel Name	Hydrologic Features	Developments	Resource Concerns
West Chinle Escarpment	-Dry Wash tanks- east end -Ramsey Slide Tank-above Ramsey Slide	-Abandoned well on mesa at east end (well type unknown) -Ranch roads	-3 mine sites of unknown condition
East Chinle Escarpment	-Saddle Horse Draw, a wash joining the Puerco 2.5 mi. N. above 9-Mile Wash -9-Mile Seep -West 9-Mile Well -3 tanks on mesa between 9-Mile Wash and -Bar-in-Well with windmill, taps alluvial aquifer	-9 earthen dam cattle tanks and corrals-along foot of escarpment to 9-Mile Wash -Ranch Roads	-Heavy developments of tamarisk in lower 9-Mile Wash -Helium well in Saddle Horse Draw Headwaters -Rock quarry
West Rim Painted Desert	-Headwaters of Wildhorse Wash -1 Unnamed tank -Little Rabbit Tank	-Drill hole (for water or gas) -Ranch Roads -4 Uranium Prospects	
Rainbow Forest Badlands	- 4 parallel badland drainages	-Abandoned section of US 180 -Current alignment of US 180	-Current alignment of US 180
Wallace Tank Ruin	-Drained by Ted's Wash -3 Tanks, Walace, West and unnamed	-Ranch Roads	
Canyon Butte Ruin	-Delaney Tank -Origin of two tributaries to Carr Lake Draw	-Ranch roads -Park water line and water line access road	

Table 1. Water-related features in lands proposed for future park additions.

IV. CONSIDERATIONS FOR FUTURE ACTIONS

- **Participate in Southern Colorado Plateau Vital Signs Monitoring Network implementation planning for "Level 1" Water Quality Inventories and the design of the long-term Southern Colorado Plateau water quality monitoring network.**

A recent Inventory Data Evaluation and Analysis (IDEA) of Petrified Forest National Park's existing water quality data indicated that very limited water quality data currently exist for the park (National Park Service, 1999). The IDEA analysis recommended that a "Level I" water quality inventory be initiated and funds for this purpose are currently available through the NPS Southern Colorado Plateau Vital Signs Monitoring Network.

It is recommended that park staff actively participate in implementation planning for the "Level I" water quality inventories and the subsequent design of the long-term water quality monitoring program. Background information from this report and subsequent "Level I" water quality inventory methods should be evaluated in order to: 1) recommend periodic monitoring of Puerco River water quality in the vicinity of the Puerco River Bridge, 2) coordinate Puerco River monitoring efforts with possible upstream USGS/state efforts (vicinity of Chandler, AZ) in order to correlate water quality conditions in the park with upstream stressors, 3) evaluate the need for continuing water quality monitoring of Puerco River Well No. 2, and 4) identify / establish priorities for any additional water quality inventory or monitoring needs within Petrified Forest National Park.

- **Develop a Water Conservation / Drought Contingency Plan and implement principles of "sustainable design" for water conservation into park operations and development.**

Historically, the water supply needed to provide visitor services, fire suppression, and the household needs of park and concession employees at Petrified Forest National Park was obtained from a number of groundwater wells within the park. This changed in 1997, however, when the park began to purchase water from the Navajo Tribal Utility Authority (NTUA). While the supplies provided by the NTUA are adequate to meet current and projected park demands, the Navajo Nation has expressed an interest in encouraging further development within the Navajo New Lands area of the reservation. The ability and willingness of the NTUA to meet long-term park demands is a concern.

Additionally, Petrified Forest National Park is located in a desert environment at the southern edge of the Colorado Plateau. The National Park Service, as one of the nation's principal conservation agencies, has a responsibility to foster the sound use of our nation's resources and has made a commitment to environmental leadership (National Park Service, 2001).

Because of this, the park is strongly encouraged to review its current policies relating to water use and conservation, and if necessary to develop a Water Conservation / Drought Contingency Plan. Petrified Forest National Park is further encouraged to consider the long-term availability and alternatives for water supply as an important factor in its general management planning process. In addition, the park is encouraged to assure that facility design and park operations are undertaken in a manner to promote compatibility with the park's desert environment by making maximum use of practicable water conservation practices. The park should also consider development of a Drought Contingency Plan.

- **Consider the need and alternatives for the long-term monitoring of heavy metal contaminants and radionuclides in Puerco Well No. 2, the park's back-up water supply.**

  Currently there are three operational wells within the park, only one of which (Puerco Well No. 2) produces water suitable for domestic use. Puerco Well No. 2, the former source of the park domestic water supply, taps the aquifer located in the alluvium of the Puerco River and is connected to a concrete reservoir which could be used as a "back-up" water supply for water provided by the NTUA. The well is currently maintained and periodically "exercised". While water quality data for the Puerco River (which should be considered the "source" water for this well) is limited, the limited data available do indicate heavy metal and radiological contamination of the water of the Puerco River.

  As the Puerco Well No. 2 is acknowledged by the park as the "backup" source for domestic water supply, it is recommended that the park consult with the U.S. Public Health Service Officer (Intermountain Support Office) and the Water Operations Branch of the NPS Water Resources Division to assess if periodic public water supply-type monitoring of the Puerco Well No. 2 would be desirable in conjunction with "Level I" Inventory or long-term water quality monitoring in order to confirm Puerco Well No. 2 as a valid back-up public water supply well or to "flag" any potential deteriorating conditions.

- **Endorse and support current research efforts to characterize the riparian community potential and evaluate areas where tamarisk control and riparian restoration efforts are most likely to result in a return to natural biological communities.**

  The invasion of the non-native tamarisk or salt cedar has been an issue of continuing concern at Petrified Forest National Park. Well intentioned efforts to eradicate tamarisk using herbicide spraying in the late 1960s and further efforts of eradication via cutting and herbicide treating in the late 1980s met with very little success. In 1996, the park initiated a Water Resources Division effort to eradicate tamarisk over a 400 acre area to be followed by the replanting of coyote willow and cottonwood. This effort, too, met with very limited success, possibly because of insufficient planning prior to restoration efforts.

  Petrified Forest National Park is strongly encouraged to endorse and support current research efforts initiated to better characterize the riparian community potential and to evaluate areas where tamarisk control and riparian restoration efforts are likely to result in a return to natural biological communities, prior to initiating future restoration attempts.

- **Incorporate the need for water-related inventory, monitoring, research and management needs into park expansion planning.**

  Once completed, the expansion of the park's boundaries as proposed in the General Management Plan (National Park Service, 1991) will likely require the inventory and monitoring of newly acquired water-related resources. The proposed boundary change will include new surface water and groundwater resources, extend the riparian corridor along the Puerco River under park jurisdiction, and possibly include water rights associated with existing wells on newly acquired lands. The park is encouraged to consider needs for additional water-related inventory, monitoring, research or management activities as a component of both the park's expansion planning efforts.

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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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